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Contents

CHAPTER 1

Robotic Surgery: Current Status

Arvind Kumar, Belal Bin Asaf, V Balasubramanium, Tarun Jindal

INTRODUCTION

The term "robot" was introduced by the Czech playwright Karel Capek in 1923. The Czech word *robata* means drudgery. In the play RUR, robots—mechanical objects designed for drudgery—take over the human race. During the 20th century, the notion of robots was a popular science fiction theme. In films, "Humanoid" (looking) robots have ranged from friendly companions to vicious predators manipulated by villains to autonomously functioning machines endangering humanity. In reality and in practical daily life, robots have revolutionized industrial production and are used to accomplish repetitive tasks precisely and without fatigue. Unlike robots of science fiction, these robots are driven by computers that are, in turn, programmed for specific tasks. Consequently, to the lay public robots are either "humanoid" looking science-fiction curiosities, or mechanical machines that are driven by digital systems without human intervention.

The mention of word "Robot" in surgery arouses fear in the minds of patients. Will you also be there in the OT or not, is the immediate question asked to the surgeon. It is mainly due to the wrong perception in the minds of the people about the nature of present surgical robotic system, which in reality, is a surgical instrument that is manipulated from a remote console by a surgeon and represents extensions of the surgeon's mind and hands. In the future, surgical robots may be directed from vastly remote locations and may even have computer-controlled or autonomous function. However, presently, surgical robots are mere instruments that are remotely manipulated by a surgeon using an electromechanical interface. Present-day surgical robots are neither autonomous nor are, they driven by preprogrammed computers.

ROBOTIC SURGERY: CURRENT CONCEPT

Surgical robotic systems grew out of the concept of telesurgery and minimally invasive surgery. The concept of telesurgery—that the surgeon did not need to be at the patient's side to conduct the operation was explored by the US military and National Aeronautic and Space Administration (NASA) in the 1970s and 1980s. Following the successful testing of this one-armed system, the Advanced Biomedical Technologies Program at the Defense Advanced Research Project Agency funded the development of a prototype surgical robotic system. The system provided an eye-hand axis similar to that of conventional open surgery and enabled a surgeon seated at a workstation across the room to move the surgical instruments. The initial thrust of this program was to develop systems that could be used to treat injured soldiers on a battlefield in remote locations around the world. This particular military application has not been realized until now. However, the concepts of three-dimensional (3D) visualization, heightened dexterity, and fine instrument manipulation were incorporated into surgical robotic systems, which moved out of the hands of the military and NASA, into commercial civil applications in the early 1990s. The first computer-enhanced surgical instrument was the RoboDoc (Integrated Surgical Systems, Sacramento, CA) in 1992. RoboDoc enabled precise drilling of the shaft of the femur by orthopedic surgeons. AESOP (automated endoscopic system for operative positioning) (Computer Motion Inc, Santa Barbara, CA) was introduced in 1994. AESOP gave the surgeon control of the video-endoscope. It provided a stable field of vision and was directed by voice commands by the surgeon. In the late 1990s, two commercial robotic surgical systems were introduced. The da Vinci robotic surgical system (Intuitive Surgical, Sunnyvale, CA) was introduced in 1997. In March 1997, the first clinical robotic procedure, a cholecystectomy, was performed by Cadiere and Himpens in Brussels, Belgium, using a da Vinci robot. The first robot-assisted cardiac procedure was performed with the da Vinci system in May 1998 and the first closed-chest coronary artery bypass graft was performed in June 1998. The da Vinci system was approved by FDA for General Surgery applications in July 2000. The Zeus robotic surgical system (Computer Motion, Santa Barbara, CA) was introduced in 1998. However, the two companies merged soon after and da Vinci system is the only Surgical Robotic System in the market since 2000 till date. Since its approval in 2000, 1933 da Vinci systems have been installed in 1560 hospitals worldwide (status June, 2011), majority in the US hospitals.

THE CURRENTLY AVAILABLE—DA VINCI SYSTEM AND ITS COMPONENTS

The da Vinci Si-surgical system (Figure 1.1) works on the Master-Slave concept and is made up of three components:

1. *Surgeon console:* The surgeon operates while seated comfortably at the ergonomically designed da Vinci Surgeon Console (Figure 1.2), viewing a 3-D image of the operative site (Figure 1.3). As the surgeon moves the master controllers at the console the instruments are performing the same movements inside the patient's body. The da Vinci Robotic System is able to scale the

Figure 1.1: Complete da Vinci Si-surgical system
(*Courtesy:* Intuitive Surgical, Inc., 2012)

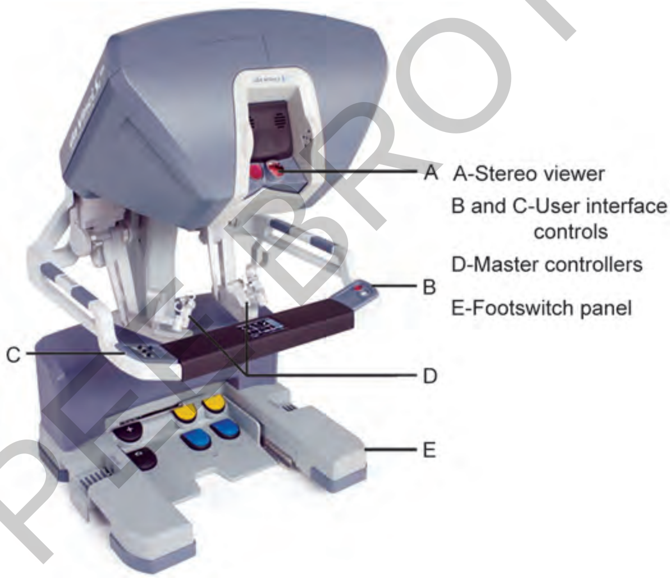

Figure 1.2: Surgeon's console
(*Courtesy:* Intuitive Surgical, Inc., 2012)

doctor's motions and translate them to the operating arms. *Instrument Control Masters* (Figure 1.4) consist of two multijoint master controls, one for each hand (the right and the left hand of the device). Each has levers for the index finger and thumb of the surgeon, which are held in place by Velcro straps. Movements at this multijoint master control are exactly replicated at the robotic arm of the patient cart and squeezing and twisting these levers together replicates the same movement at the instrument tip.

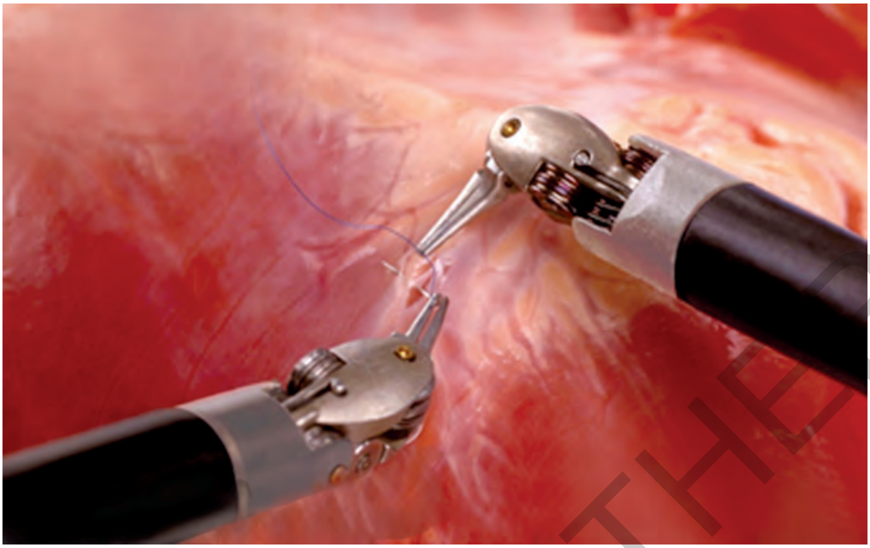

Figure 1.3: Binocular 3-D Vision
(*Courtesy:* Intuitive Surgical, Inc., 2012)

Figure 1.4: Instrument control masters
(*Courtesy:* Intuitive Surgical, Inc., 2012)

2. *The patient (robotic) cart:* The patient cart in da Vinci Si model consists of 4 arms, all of which are mounted on a maneuverable wheel base (Figure 1.5). The cart is connected to the Master console by means of color coded cables, through which it is connected to the main power circuit. Each of the robotic arm has multiple joints, resembling the human arm with a shoulder (setup joint), an elbow (instrument clutch button), and a wrist (effector

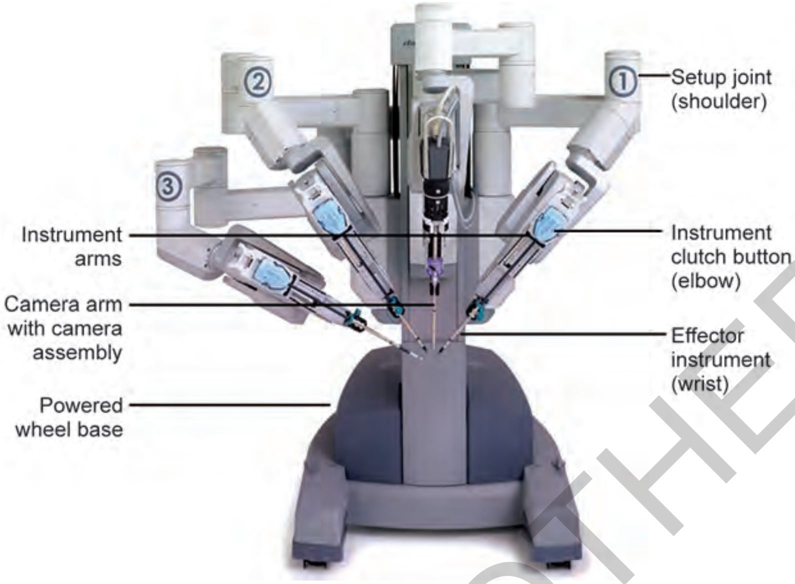

Figure 1.5: Patient cart
(*Courtesy:* Intuitive Surgical, Inc., 2012)

instrument) (Figure 1.6).These setup joints are provided with release buttons for manual positioning of the arms. Pressing on these buttons, the arm's position can be adjusted as desired through different degrees of flexion at the joint. The instruments are attached to a carriage on the robotic arm, which moves the instrument in and out of the port. This acts as the elbow of the robotic arm and pivots at the entry point into the specific body cavity. One of the 4 arms, the camera arm has a mount for the camera and is compatible with a standard 12 mm port. The rest of the 3 arms, are compatible with a specially designed 8 mm metallic port, provided with sharp and blunt trocars, which come with the system. All the 4 arms are mechanically and electronically balanced on the base for maximum safety. Also available are disposable custom made sterile plastic drapes for the arms to ensure sterile operating field. The movements of the arms are controlled by the masters at the Master console. The robot system is provided with a wide variety of specially designed instruments (Figure 1.7). The instruments are provided with a wrist (EndoWrist® technology, Intuitive Surgical Inc.), which is controlled by a cable system connected to four wheels on the instrument's head, that can be moved simultaneously by the robot to produce a single complex movement mimicking the motion of the human wrist. The wrist in the instrument provides six degrees of freedom at the instrument tip and the seventh degree of freedom is provided by the instrument (Figure 1.8). Each of the instruments can be used for 10 sessions only, a count which is maintained by the system. Following this the instruments

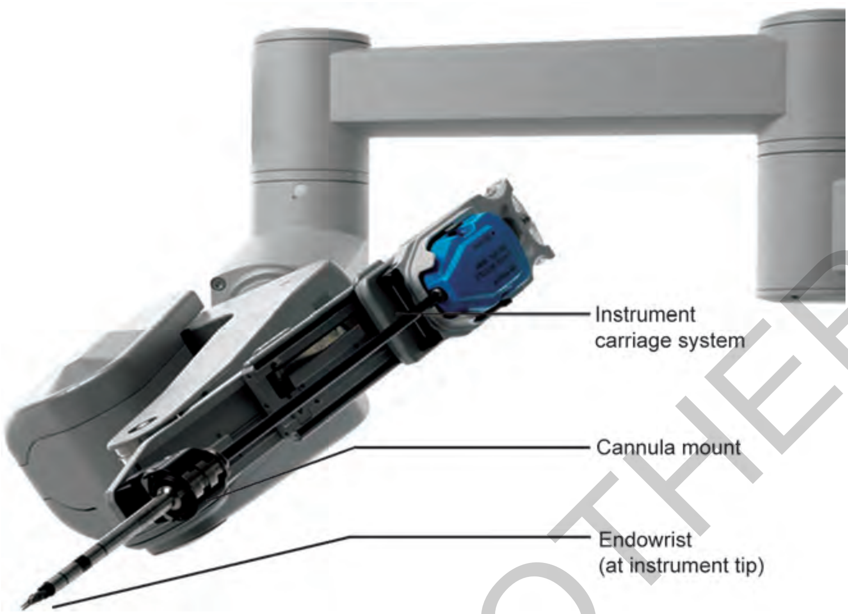

Figure 1.6: Robotic instrument arm—with mounted instrument (*Courtesy:* Intuitive Surgical, Inc., 2012)

Figure 1.7: Robotic instruments

Figure 1.8: Seven degrees of movement (Endowrist technology)

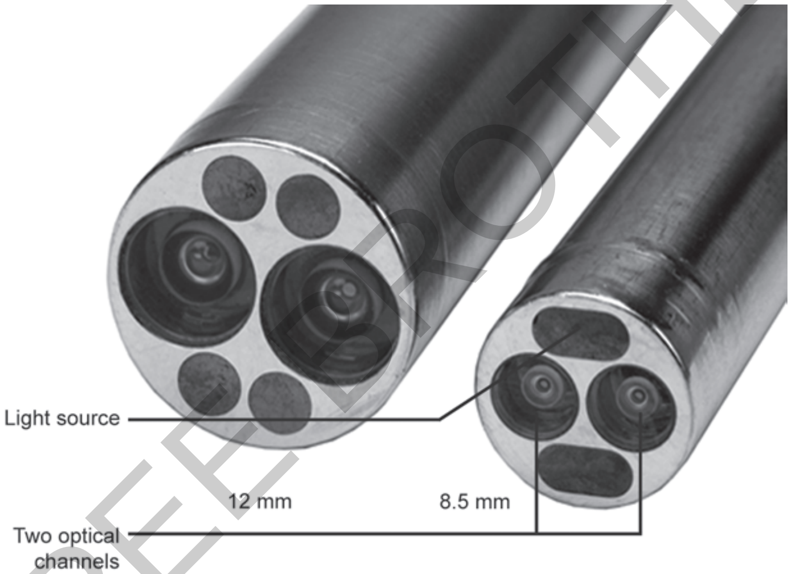

Figure 1.9: Insite Vision system—endoscope
(*Courtesy:* Intuitive Surgical, Inc., 2012)

needs to be discarded. The instruments can be sterilized and reused for the limited ten counts. There is also possible risk of instrument cable breaking off even before the 10 sessions.

3. *The Vision Cart with Insite Binocular Vision System with high resolution 3-D endoscope:* This component provides true 3-D images of the operative field. Operative images are enhanced, refined and optimized using image synchronizers, high intensity illuminators and camera control units during the course of the robotic assisted surgery.

The Binocular vision system uses dual, high resolution 3-chip cameras which are mounted on a telescope (12 and 8.5 mm) (Figure 1.9). This telescope has

Figure 1.10: Vision cart
(*Courtesy:* Intuitive Surgical, Inc., 2012)

dual viewing channels (each connected to a camera) and twin light channels providing two independent optical systems representing the right and left eye of the surgeon. The two independent optical systems project to the binocular viewer at the surgeon console, providing the 3-D stereoscopic vision to the surgeon. The surgeon controls the level of magnification by adjusting the depth of camera insertion in the operating field. 3-D image, reconstructed from the input from the two cameras is displayed on a binocular screen on the surgeon's console.

The vision cart (Figure 1.10) is composed of several components:

- *The Core* (Central processing point for the system)
- *The Illuminator* (Light source for endoscope view)
- *The Camera Assembly* (Provides the HD 3-D view)
- *The Camera Control Unit* (Carries out image processing)
- *The Touch Screen* (Which provides audio and video control patient side)
- *The Tank Holders* (Support insufflation tanks).

The control system is connected in turn to the camera and the console. The system is also provided with an emergency backup power, lasting for 5 minutes in case of power failure.

Setting up the Robot (Docking)

The Master console is connected to the main power supply and the system is switched on by pressing on the SYSTEM on the user switch panel. The system start up sequence includes an initial self-test sequence. The surgical arm homing maneuvers are initiated, during which the system will move the arms to calibrate the neutral position for each arm. Then the system initiates a mechanical integrity test for the wire rope cables in each arm. Once this is completed, each of the four arms is draped with the sterile drapes. The sterile drapes for the instrument arms are provided with an instrument adapter reinforcement, to which a sterile instrument adapter is attached. After draping, the four rotating heads on the instruments should synchronize with the rotating discs provides on the adapter. The cannula mount through which the arm is connected to the port, is then attached to the instrument arm. In the same way, camera arm is also draped and the camera mounts is attached. The draped patient cart is then covered with a sterile sheet to prevent it being contaminated. The camera and endoscopic vision systems are calibrated, white and black balancing done before every use to ensure excellent image quality. The endoscope is then attached to a sterile camera adapter, which is then passed through a sterile drape and connected to the camera head. The endoscope alignment target is attached to the end of the endoscope and the stereo viewer on the console. A 30-degree endoscope will need to be calibrated both in the up-viewing and down-viewing positions. Once all this is done the system is put in the standby mode.

The patient is then positioned on the operating table in the appropriate position desired for the specific surgery to be performed. Once the patient is anesthetized and ready for surgery, painting and draping of the patient is done in an aseptic technique, and the patient cart is positioned close to the operating table. The arms are then moved manually by using the clutch button provided near each joint in the arm and the arms of the robot are appropriately positioned. The cannula mounts are then connected to the appropriately placed ports on the patient. Once the arms are connected to the patient, further movement of the patient cart is contraindicated. The instruments are then connected to the instrument arm and the camera to the camera arm by the assisting surgeon with the help of the scrub nurse. The surgeon takes his place at the Master console, placing his head in the binocular vision area and elbows on the padded rest bars. The fingers are placed in the space provided in the levers of each masters, the right and the left, and starts the surgery by looking through the binocular viewer. The head rest is provided with an infrared sensor which enables the engaging of the instrument and the camera. On removing the head from the binocular area, the instrument as well as the camera arm gets disengaged from the master control. This safety feature is provided in the system to avoid inadvertent instrument movement and injury, when the surgeon is not viewing the operative field. The system is also provided with an audio intercom system, which enables the surgeon's voice to be heard loud and clear in the operating room. Through this the surgeon can give instructions to the assistant and scrub nurse while looking into the binocular viewer.

Undocking

When the surgery is completed or when conversion is needed, the surgeon presses the stand by button on the control panels provided in the Master console. This causes the robotic arms to disengage from the master controls. The instruments placed within the ports are removed and the arms are separated from the ports at the cannula mounts and the patient cart is moved aside. The patient can be repositioned if necessary and the surgery can be continued in the desired way. The whole procedure of undocking takes not more than 2-3 minutes in the hands of a trained team.

Advantages of Robotic Surgery over "Conventional Laparoscopy"

The last two decades experienced a revolution in the surgical technique namely Minimal access surgery (MAS), aimed at reducing patients' pain and recovery time from surgical procedures by minimizing the trauma of the large incisions required in conventional open surgery. However, on the flip side, the MAS has made the otherwise simple procedures into technically complex ones due to reasons mentioned below:

Loss of Stereoscopic Depth Perception

Vision in MAS is limited to two dimensions, losing the depth dimension of binocular vision. Though few stereoscopic endoscopes do exist, their performance is limited in resolution and contrast both at the endoscope level and at the display level.

Loss of Natural Hand Eye Coordination

With the introduction of MAS, the surgeon operates seeing at a display unit rather than at his own arms. The camera control is in the hands of the assistant who may not always and rapidly follow the Surgeon's maneuvers leading to the desired field of vision being lost by the surgeon at critical moments. This becomes extremely important in bleeding and other emergency situations.

Loss of Dexterity and Intuitive Movement

Laparoscopic instruments are long, rigid and cumbersome and operate on a fixed fulcrum at the point of entry of the trocars. These results in limited range of motion, diminished tactile feel, and exaggeration of the surgeon's natural tremor. As the direct result of pivoting far away from the operative site, the conventional endoscopic instruments have restricted access to non-contiguous structures, and reverse or counter intuitive response at the instrument tip in relation to the movements of the surgeon's hand. (i.e. to move the Instrument tip to right,you have to move the handle outside to left). They also lack the wrist like human hand. All these with loss of the few degrees of freedom from

6 degrees to 2 degrees of freedom further compromise on the dexterity during the laparoscopic procedure. Suturing and knot-tying are difficult. Appropriate tension is difficult to achieve when intracorporeal knots are tied by instruments that have a fulcrum point at the trocars site rather than the target tissue. Furthermore, the long length of the instruments compromises ergonomics and thereby contributes significantly to surgeon fatigue and longer learning curves.

The above mentioned short comings of Minimal Access Surgery have been addressed by the Intuitive Surgical Inc., Sunnyvale, CA in the da Vinci surgical system. This system restores the faculties lost when using MAS techniques, while maintaining the advantages of MAS. These are:

Stereoscopic Depth Perception (3D Visualization)

The da Vinci robot system uses a two-channel endoscope which sends both a left and right eye image back to the surgeon, essentially functioning as an extension of the surgeon's eyes. Moreover, the robotic camera is controlled by the surgeon, and held in a steady position without fatigue or delay in movement. The magnification provided by the system actually delivers to him an image even better than open surgery.

Improved Hand Eye Coordination

The alignment of the surgeon's hand motions to the motion of the surgical tool tips is both visual and spatial. For visual alignment, the system projects the image of the surgical site atop the surgeon's hands and to achieve spatial alignment, the system software aligns the motion of the tools with the camera frame of reference. Put together, the visual and spatial alignment make the surgeon feel as though his hands are inside the patient's body while performing the surgery.

Dexterity and Intuitive Movement

The da Vinci robot system restores the degrees of freedom lost in conventional laparoscopy by use of Endo Wrist® technology, placing a wrist with three degrees of freedom inside the patient and controlling it naturally, bringing a total of seven degrees of freedom to the control of the tool tip (3 of orientation, 3 of translation, and 1 of grip). Motion scaling, another novel feature of the system is the ability of the system to scale down large movements made by the surgeon on the master console to smaller movements made by the ''slave'' arm and instrument tip (Figure 1.11) For example, a 5:1 scale factor maps 5 cm of movement on the masters into 1 cm of movement at the slaves. The robot uses software that electronically allows for large, coarse motions of the surgeon's hand to be translated into fine movements by the instruments. This enables extremely fine dissection, precise suturing, and maneuvering in awkward and narrow anatomic locations. There is no fatigue factor in the robotic arms and

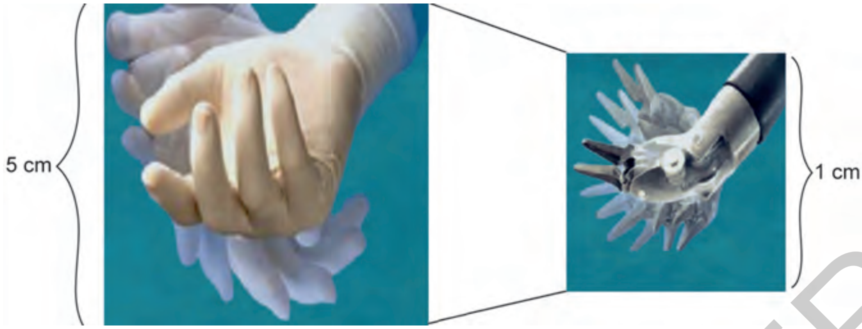

Figure 1.11: Motion scaling (5:1 Ratio)

Surgeon can operate and perform most complex tasks even in awkward anatomic locations without getting tired. The ergonomic sitting position for the surgeon at the master console further reduces the fatigue factor, which is VITAL in complex Surgeries.

CURRENT CLINICAL APPLICATIONS

The robots were initially used by the cardiothoracic surgeons. It was later on used on experimental basis, in prostate surgery initially. With the FDA approving the use of robot in the field of urology, it is clinical applications and installations expanded exponentially over the next few years. At present robot is used for minimal access surgery in a wide range of specialties, from general surgery, urology, gynecology, cardiac, thoracic and vascular surgery, oral and maxillofacial surgery, endocrine surgery to head and neck surgery, with almost all procedures which were performed by conventional minimal access surgery being successfully carried out with robotic-assistance. Robotic surgery has been proved to be feasible and safe for all operations across various surgical disciplines, though its advantages over conventional minimal access surgery still need to be established in most of these procedures.

Robotics in Urology

The maximal use of robot has been in the field of urology. The first reported use of robot in urological procedure dates back to 1989, when Davies et al used an "industrial robot" to perform transurethral resection of the prostate (TURP).[1] Experience with the da Vinci system started with prostate cancer surgery. Slowly and progressively, robot has found its application in all procedures in urology like prostatectomy, radical cystectomy with lymph node dissection, renal resections–partial/total, pelviuretric junction reconstructions and many more.

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Salient Features

- Provides an up-to-date review of the surgical progress
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- Includes the chapters on the evidence-based clinical guidelines which are extensively referenced
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Puneet MS DNB(Surg) MNAMS FACS completed his graduation (1995) and postgraduation (1998) from Institute of Medical Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, India. He obtained DNB in Surgery from National Board of Examination, and was a Senior Registrar in Ram Manohar Lohia Hospital, New Delhi, India. Thereafter, he has worked in different hospitals in various capacities. He was appointed as the Assistant Professor (2003) and the Associate Professor, Department of Surgery, Institute of Medical Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, India. He has presented several papers at conferences and given lectures in various countries. He worked as a Surgical Fellow in the Liver Unit, Queen Elizabeth Hospital, Birmingham, UK, to gain experience in Hepatobiliary Surgery. He has published more than 50 national and international papers, authored 3 books and written 12 chapters in various publications. He is also a Fellow of the American College of Surgeons, Chicago, and Recipient of citation from Oklahoma, USA.

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